An Appraisal of OAK WILT CONTROL PROGRAMS In Eastern United States

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OAK WILT CONTROL PROGRAMS

In Eastern United States

Oak wilt control programs have been carried on by a number of eastern states for the past 10 years. The Forest Service, through its Division of Forest Pest Control, has cooperated in most of these. The larger programs have been partially supported with Federal funds made available through the Forest Pest Control Act, and Forest Experiment Station personnel have conducted studies to evaluate and compare the effectiveness of the various control methods. The following report presents the results of these studies.

The wilt disease of oaks caused by the fungus *Ceratocystis fagacearum* (Bretz) Hunt, is present in a 20-state area in the central and eastern United States. It threatens the most valuable component of the hardwood stands of this area, oak comprising more than a third of the total hardwood growing stock and sawtimber volume. All commercially important oak species are susceptible. Although oak wilt was discovered in 1944, it was not until the early 1950's that its widespread distribution was recognized and control appeared to be urgent.

The decision to attempt control was made despite rather critical gaps in our understanding of the epidemiology of the disease and etiology of the fungus. The infected tree was considered the source of inoculum for disease spread with the fungus occurring there as endoconidia and mycelium distributed in the outer sapwood, inner bark, and roots. Also, in some areas, fungus mats were frequently produced on wilt-killed trees. These mats are localized accumulations of fungus mycelium and spores between the wood and bark. They produce an odor attractive to insects and as they enlarge, the bark cracks open exposing them to potential vectors. Ascospores of the fungus have been found only on these mats.

Disease spread was known to occur through root grafts connecting diseased and healthy trees and also above ground for greater distances. The nature and identity of the agents responsible for aboveground spread and the relative importance of root-graft spread were poorly understood. However, it was judged that application of control measures based on incomplete knowledge of the disease was preferable to allowing the fungus to spread unchecked, and that methods could be altered as improved techniques were developed through research and experience. The control techniques that evolved were the product of the thinking and experience of many scientists representing a number of agencies and institutions. Several different methods were adopted but all had in common the biologically sound objectives of reducing the abundance or controlling the dispersal of fungus inoculum at its source.

DETECTION AND CONTROL METHODS

The control projects with which this report is concerned are those of Kentucky, North Carolina, Pennsylvania, Tennessee, and West Virginia. The methods adopted by each of these states are as follows:

KENTUCKY

Detection.—An aerial detection survey providing complete coverage of the infected portion of the State was made once each year. This was supplemented by ground surveys incidental to on-site checking of all suspect trees located from the air and revisits to known infection centers of previous years.

Control.—Diseased trees were felled and sprayed with a mixture of persistent insecticides (DDT and BHC in fuel oil) to reduce insect invasion and to kill fungus-carrying insects as they emerged from the tree, thus preventing their flight to healthy trees and the associated risk of disease spread. Stumps of diseased trees were sprayed with the same mixture plus 2,4,5-T. The herbicide 2,4,5-T was added to the spray to inhibit stump sprouting and hasten root kill, thus shortening the period during which these parts of the diseased tree would provide a reservoir of inoculum.

NORTH CAROLINA AND TENNESSEE

The detection and control methods used in these states were basically the same.

Detection.—Aerial surveys providing complete coverage of special areas used in each state for control study purposes were made annually. These were supplemented by ground surveys incidental to on-site checking of all suspect trees located from the air and revisits to known infection centers of previous years.

Control. — Diseased trees were felled and the tree and stump sprayed with a mixture of DDT, BHC, and pentachlorophenol in fuel oil. Ammate crystals were placed on the stump and in notches cut into the buttress roots. The purpose of spraying the diseased trees and stumps was the same as stated for Kentucky. Pentachlorophenol, a fungicide, was added to the spray to obtain direct kill of the fungus. The stump was treated with ammate, a herbicide, to inhibit sprouting and hasten root kill.

PENNSYLVANIA

Detection.—An aerial detection survey providing complete coverage of the infected portion of the State was made once each year. The more heavily infected portions were resurveyed from two to five times each year. Supplementary ground surveys were made incidental to on-site checking of all suspect trees located from the air and revisits to known infection centers of previous years.

Control.—Diseased trees and all trees of the same species group

as the diseased tree (red oak group or white oak group) and within 50 feet of the diseased tree were felled. The stumps of all trees so cut were treated with ammate crystals. Diseased trees were cut to hasten drying and thus reduce fungus-mat production. Root grafting in oaks occurs most frequently between trees of the same species or species group. Healthy trees surrounding the infected trees were cut and poisoned to prevent spread of the fungus through root grafts. This also eliminated many of the nearest suscepts for aboveground spread of the disease.

WEST VIRGINIA

Detection.—An aerial detection survey providing complete coverage of the entire State was made twice each year. The more heavily infected areas were resurveyed at 2-week intervals throughout the summer season. Ground surveys were made incidental to on-site checking of all suspect trees located from the air and revisits to known infection centers of previous years.

Control.—A deep girdle was chopped into the heartwood around each diseased tree at a convenient height. The bark on the base of the tree and buttress roots from the girdle to ground line was removed. The purpose of the deep girdle and basal bark removal was to hasten drying of the diseased tree, thus preventing or reducing fungus-mat formation.

POST CONTROL APPRAISAL

Once the programs were in operation the need to evaluate their effectiveness was evident, particularly since none of the methods had been thoroughly tested and they were based largely on premises rather than proven facts. The Oak Wilt Post Control Appraisal Study (a cooperative undertaking between the states of Kentucky, Maryland, North Carolina, Pennsylvania, Tennessee, and West Virginia, and the Northeastern, Southeastern, and Central States Forest Experiment Stations and the Division of Forest Pest Control of the Forest Service) was designed to fill this need.

The effectiveness of the various control measures was appraised by two methods. These involved measuring and comparing the effects of control versus no control on small permanent plots and on large county-sized areas.

In the first method, small appraisal plots, 2.9 acres in size, were selected to meet the following specifications:

1. The plot to be round, 400 feet in diameter, with an oak wilt infection center[1] as close to the center of the plot as possible.

2. The infection center to consist of not more than five wilting or wilt-killed trees, at least one of which was of the red oak group, 6 inches d.b.h. or larger, wilting at the time the plot was established. Approximately half the plots to be established around single-tree centers.

3. At least five healthy oaks of the red oak group, 2 inches d.b.h. or larger, to be within 50 feet of the infected oaks with comparable oak stocking on the remainder of the plot.

4. Each center to be at least 500 feet away from any other known oak wilt center or dead wilt suspect.

Because of difficulties in meeting these exacting standards, these specifications were later amended to allow establishment of partial plots around centers at the edge of a stand, at the edge of an opening in a stand, or at the edge of an oak-stocked area within a stand. Such plots had to meet all other specifications and could not exceed one-fourth of the total number of plots established.

North Carolina and Tennessee, using identical survey and control methods, were considered as one unit in the study. One county in North Carolina and one county in Tennessee, each within their respective state-control units, were selected for control-plot establishment. Check plots were established in another Tennessee county in which no oak wilt control was attempted (fig. 1).

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[1] *The term "oak wilt infection center" as used in this report refers to a single wilt-infected or wilt-killed tree or a group of such trees, any one of which is not more than 50 feet from another wilt tree. A wilting tree more than 50 feet from other wilt trees is in a separate infection center.*

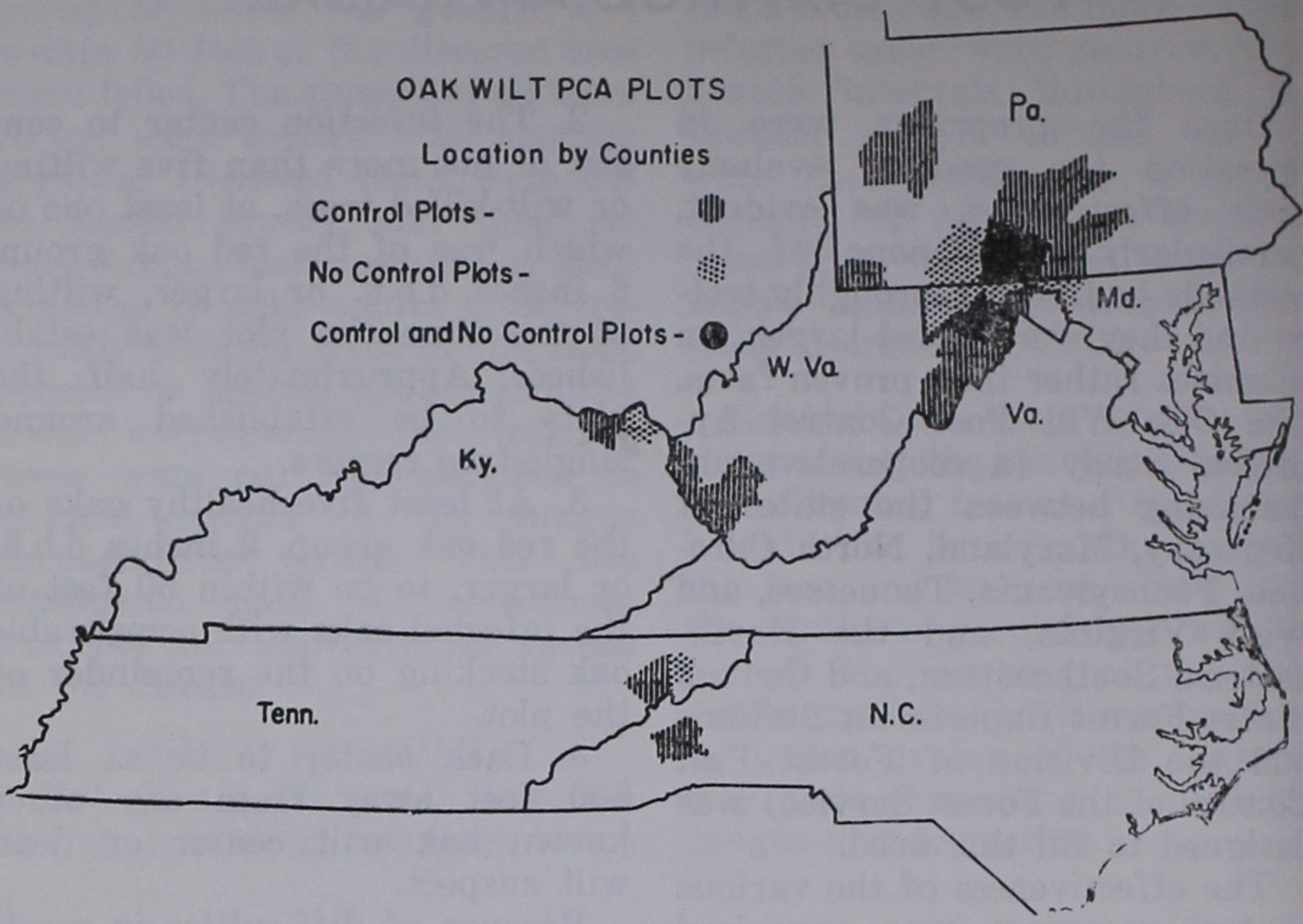

FIGURE 1. — Oak wilt PCA plots — location by counties.

In Kentucky, two adjoining counties were chosen for appraisal-plot location. One county was included and the other excluded from the state-control program. Control plots were established in the former and check plots in the latter.

Because of the presumed high hazard of leaving untreated infection centers, a single set of check plots was established for Pennsylvania and West Virginia. These were to be located in the three adjacent western-most counties in Maryland where only token control was being attempted in any event. Since it turned out to be impossible to find a sufficient number of plots in this area, additional check plots were later established in south-central Pennsylvania and northeastern West Virginia. All of these plots served as common checks for both states. All wilt infections in these areas, except those designated as check plots, were treated by their respective state-control method.

The control plots in Pennsylvania were located in 12 counties in the south-central and western part of the State. The control plots in West Virginia were established in six counties in the northeastern and four counties in the southeastern part of the State.

All appraisal plots were planned to be established over a 3-year period starting in 1958 (table 1). Unforeseen problems in plot location and establishment extended this period to 4 years in some areas.

All plots were stem mapped at time of establishment to show the location of wilt-infected and dead trees. Each plot was carefully examined on the ground each summer through 1963 to locate subsequent disease spread. Thus, the incidence of oak wilt is recorded for all plots for periods ranging from 2 to 5 years. On control plots, diseased trees present at the time the plot was established and those found in succeeding years were treated by the state-control method applicable to the plot location. On check plots, diseased trees were recorded but not treated. Treatments were applied by regular state crews in the same manner as any other wilt center in their overall control program. Plots were established and surveyed annually by special crews responsible to the respective U.S. Forest Service Experiment Stations.

The second appraisal method in which the effects of control versus no control were compared on county-sized units was made in only two states, Tennessee and Kentucky. The annual incidence of oak wilt was measured by aerial survey and ground checking in a pair of adjoining counties in each state. The diseased trees in one county of each pair were treated by the state-control method. No control was attempted in the other county of each pair.

TABLE 1.—Number of post control appraisal plots by location and type

Location	Type: Control	Type: Check
North Carolina-Tennessee	53	37
Kentucky	60	60
Pennsylvania	56	--
West Virginia	70	--
Maryland-Pennsylvania-West Virginia	--	61
Total	239	158

RESULTS AND DISCUSSION

The study data have been summarized in many different ways. All methods provide essentially the same picture of results. Those presented here were chosen because they appear to be the most logical or the most easily understood. Some plots were lost due to fire or cutting during the course of the study. The data from such plots are included, however, for so long as they met specifications. There were approximately the same number of partial plots among the control as among the check plots and data from these are included without special identification.

The pattern of oak wilt spread on the untreated check plots (fig. 2) is significant in interpreting the results of control treatments. The preponderance of local spread[2] as opposed to long-distance spread[3] is obvious. Ninety-one percent of all wilting trees in the Tennessee check plots and 82 percent in the Pennsylvania-Maryland-West Virginia check plots were within the local-spread zone. The ratio of local to long-distance spread more nearly approached a balance in Kentucky where 59 percent of all wilted trees were within 50 feet of previously wilted trees. However, considering the difference in area between the local and long-distance-spread zones, this still represents a highly localized pattern of disease transmission. Although long-distance spread was recorded for a maximum distance of only 200 feet from sources of inoculum, the data suggest that the relative abundance of local and long-distance spread shown here would not be greatly altered by sampling much larger areas.

It may therefore be concluded that the characteristic pattern of oak wilt spread, so important from the standpoint of control, is one of a preponderance of transmission for short distances from sources of inoculum and relatively infrequent transmission to greater distances.

To measure the effectiveness of the control treatments, oak wilt incidence or severity on the control and check plots are compared. This may be measured in terms of the number of wilting trees per plot per year. It may also be logically argued that a single infection center with two wilting trees represents a lower degree of disease severity than two infection centers of one tree each and that the number of active infection

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[2] *"Local spread" is when a tree not more than 50 feet from a previously wilted tree becomes infected. Such spread may be due to either aboveground or root-graft transmission of the fungus.*

[3] *"Long-distance spread" is when a tree more than 50 feet from a previously wilted tree becomes infected. Such spread is considered to be beyond the limits of root-grafting and hence invariably due to some other means of transmission.*

centers[4] per plot per year is a better measure. Both criteria of disease severity are presented in the following evaluations.

In the first summary (table 2), the average number of active infection centers per plot is listed for the first, second, third, fourth, and fifth years after plot establishment. Included in these figures are centers active due to local spread at the original center, long-distance spread within the original plot boundaries but resulting in new centers, and subsequent local spread at these new centers. The grouping of data by plot age tends to average the "normal" year-to-year fluctuations of wilt incidence; i.e., since plots were established over a 4-year period, they become of the same age in different calendar years. The average number of active centers per plot per year for all years is also shown. Comparison between the results of control and no control is presented in two ways: (1) the difference between the average number of active centers per plot per year on control plots and check plots and (2) "percent control" which is this difference expressed as a percentage of the average number of active centers per year on check plots.

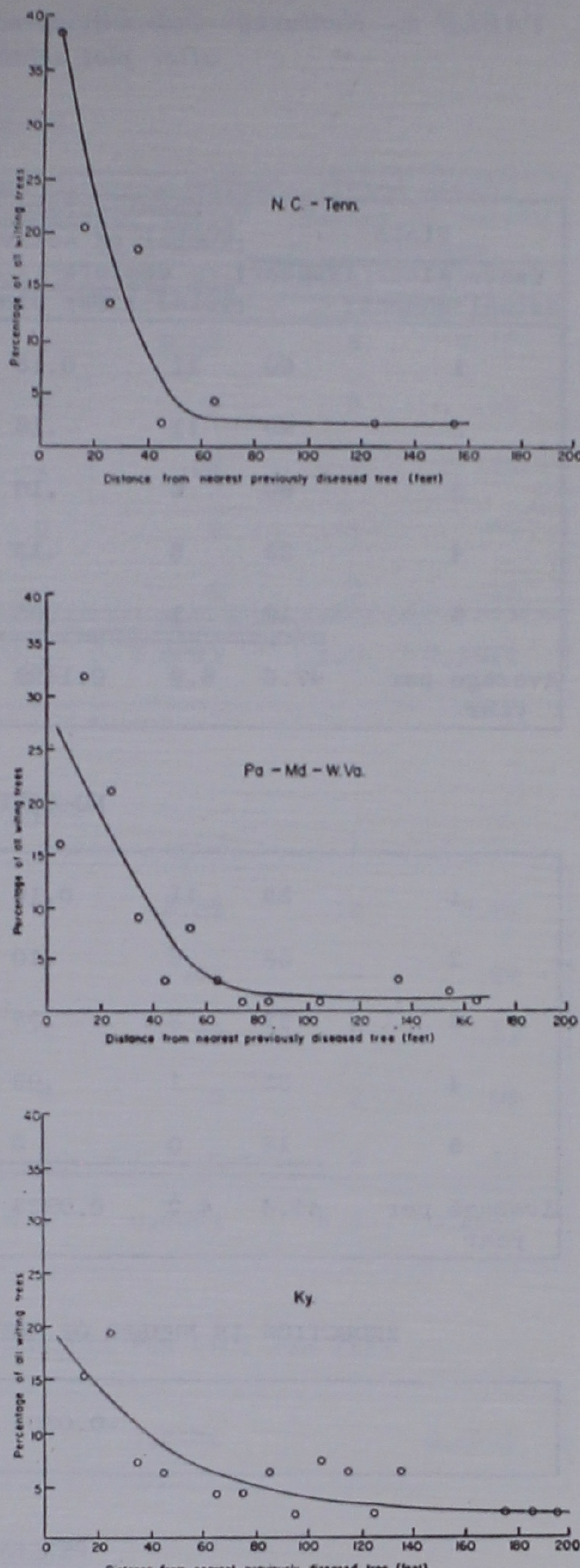


FIGURE 2. — Frequency distribution of oak wilt trees by distance from nearest previously diseased tree, 1959-1963.

[4]*An "active infection center" is one with a currently wilting tree.*

TABLE 2.—Kentucky—Oak wilt spread on control and no-control plots by years after plot establishment, 1959-1963

CONTROL PLOTS

Plots		Local spread: Number of active centers		Long-distance spread: Number of active centers		Total spread: Number of active centers	
Years after establishment	Number	Total	Per plot	Total	Per plot	Total	Per plot
1	60	11	0.18	7	0.12	18	0.30
2	60	11	.18	5	.08	16	.27
3	60	6	.10	4	.07	10	.17
4	39	5	.13	0	0	5	.13
5	19	1	.05	0	0	1	.05
Average per year	47.6	6.8	0.1429	3.2	0.0672	10.0	0.2101

NO-CONTROL PLOTS

1	59	11	0.19	10	0.17	21	0.36
2	58	6	.10	4	.07	10	.17
3	57	3	.05	6	.11	9	.16
4	35	1	.03	1	.03	2	.06
5	18	0	0	0	0	0	0
Average per year	45.4	4.2	0.0925	4.2	0.0925	8.4	0.1850

REDUCTION IN NUMBER OF ACTIVE CENTERS PER PLOT PER YEAR

			-0.0504		0.0253		-0.0251

PERCENT CONTROL

			-54		27		-14

TABLE 2.—North Carolina-Tennessee—Oak wilt spread on control and no-control plots by years after plot establishment, 1959-1963

CONTROL PLOTS

Plots: Years after establishment	Plots: Number	Local spread: Number of active centers: Total	Local spread: Number of active centers: Per plot	Long-distance spread: Number of active centers: Total	Long-distance spread: Number of active centers: Per plot	Total spread: Number of active centers: Total	Total spread: Number of active centers: Per plot
1	52	7	0.13	1	0.02	8	0.15
2	52	8	.15	0	0	8	.15
3	48	6	.12	1	.02	7	.15
4	30	1	.03	0	0	1	.03
5	22	2	.09	0	0	2	.09
Average per year	40.8	4.8	0.1176	0.4	0.0098	5.2	0.1274

NO-CONTROL PLOTS

1	37	8	0.22	2	0.05	10	0.27
2	35	9	.26	1	.03	10	.29
3	31	6	.19	1	.03	7	.23
4	23	2	.09	0	0	2	.09
5	15	2	.13	0	0	2	.13
Average per year	28.2	5.4	0.1915	0.8	0.0284	6.2	0.2199

REDUCTION IN NUMBER OF ACTIVE CENTERS PER PLOT PER YEAR

0.0739	0.0186	0.0925

PERCENT CONTROL

39	65	42

TABLE 2.—Pennsylvania—Oak wilt spread on control and no-control plots by years after plot establishment, 1959-1963

CONTROL PLOTS

Plots: Years after establishment	Plots: Number	Local spread (Number of active centers): Total	Local spread: Per plot	Long-distance spread (Number of active centers): Total	Long-distance spread: Per plot	Total spread (Number of active centers): Total	Total spread: Per plot
1	55	4	0.07	4	0.07	8	0.15
2	53	3	.06	3	.06	6	.11
3	40	1	.02	3	.07	4	.10
4	27	0	0	1	.04	1	.04
5	10	1	.10	0	0	1	.10
Average per year	37.0	1.8	0.0486	2.2	0.0595	4.0	0.1081

NO-CONTROL PLOTS

1	60	20	0.33	6	0.10	26	0.43
2	59	21	.36	3	.05	24	.41
3	25	11	.44	3	.12	14	.56
4	21	9	.43	0	0	9	.43
5	5	3	.60	1	.20	4	.80
Average per year	34.0	12.8	0.3765	2.6	0.0765	15.4	0.4529

REDUCTION IN NUMBER OF ACTIVE CENTERS PER PLOT PER YEAR

			0.3279		0.0170		0.3448

PERCENT CONTROL

			87		22		76

TABLE 2.—West Virginia—Oak wilt spread on control and no-control plots by years after plot establishment, 1959-1961

CONTROL PLOTS

Plots: Years after establishment	Plots: Number	Local spread: Number of active centers: Total	Local spread: Number of active centers: Per plot	Long-distance spread: Number of active centers: Total	Long-distance spread: Number of active centers: Per plot	Total spread: Number of active centers: Total	Total spread: Number of active centers: Per plot
1	70	18	0.26	5	0.07	23	0.33
2	69	11	.16	0	0	11	.16
3	68	12	.18	3	.04	15	.22
4	45	7	.16	1	.02	8	.18
5	15	1	.07	2	.13	3	.20
Average per year	53.4	9.8	0.1835	2.2	0.0412	12.0	0.2247

NO-CONTROL PLOTS

1	60	20	0.33	6	0.10	26	0.43
2	59	21	.36	3	.05	24	.41
3	25	11	.44	3	.12	14	.56
4	21	9	.43	0	0	9	.43
5	5	3	.60	1	.20	4	.80
Average per year	34.0	12.8	0.3765	2.6	0.0765	15.4	0.4529

REDUCTION IN NUMBER OF ACTIVE CENTERS PER PLOT PER YEAR

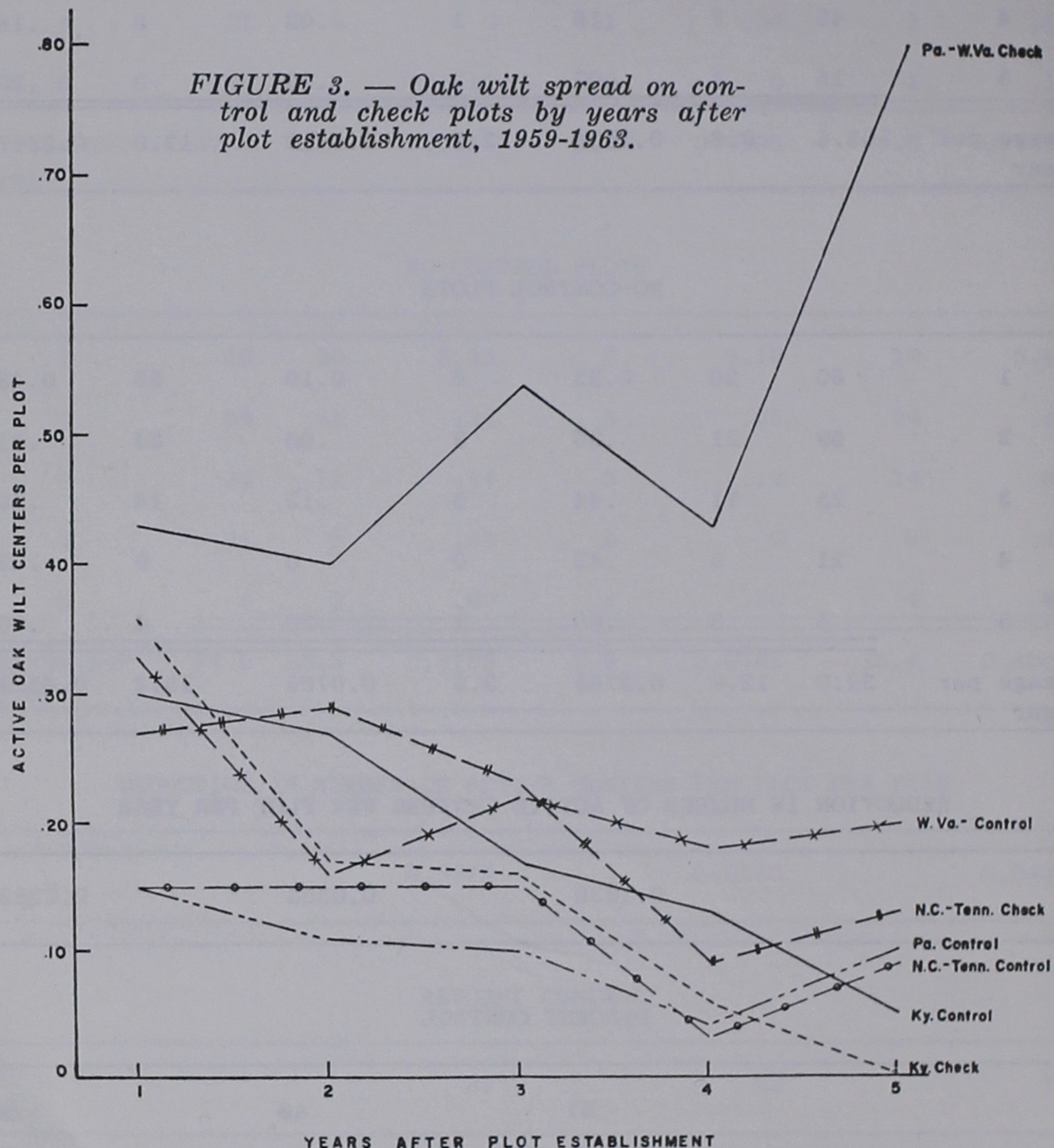
			0.1930		0.0353		0.2282

PERCENT CONTROL

			51		46		50

Several significant observations can be made from these summaries. On control plots and check plots the rate of disease spread, i.e., the number of active centers per plot per year, decreased with time, with the notable exception of the Maryland - Pennsylvania - West Virginia check plots. There, the reverse was true and the rate of disease spread increased as time passed. The difference is even more apparent in the graphic presentation of these data (fig. 3). Note that the lines representing oak wilt incidence for all plots regardless of treatment or location are relatively similar except for the aforementioned check plots. If these plots accurately represent the uncontrolled oak wilt situation in Maryland, Pennsylvania, and West Virginia, then the potential for disease buildup and damage is much greater there than in the other study areas.

FIGURE 3. — Oak wilt spread on control and check plots by years after plot establishment, 1959-1963.



In Kentucky, the frequency of oak wilt spread was greater on the control plots than on the check plots in all but the first year after plot establishment. Long-distance spread was reduced on control plots but this was more than offset by the lack of control of local spread. There is no evidence that this program exerted any controlling influence on the overall incidence of oak wilt.

In the North Carolina-Tennessee area, total oak wilt spread was reduced by the control treatment in every year of the study. The 65-percent reduction in long-distance spread is the greatest degree of control recorded for this type of spread for any of the methods. Satisfaction with this result must be tempered, however, by recognizing that long-distance spread occurred only four times on Tennessee check plots where no control was attempted.

In West Virginia, total oak wilt spread was also reduced by the control treatment in every year of the study. The deep-girdle method used there appeared about equally effective against local and long-distance spread.

The greatest degree of overall control, 76 percent, was accomplished on the Pennsylvania plots. Although this method had the poorest record of the four against long-distance spread it was very effective in preventing local spread. In this treatment, all of the healthy trees in the local-spread zone of the same species group as the diseased tree were supposed to be felled and poisoned. Therefore, local spread could occur in only two ways—from a tree of one species group to trees of the other species group or to trees left standing through error in application of the control measures. The latter circumstance explains nearly all of the local spread that was recorded on these plots.

The degree of control of all oak wilt spread for the four areas and methods appraised ranges from 0 upward to 76 percent and this degree of control is largely a reflection of the effectiveness of the treatment against local-disease spread (table 3). This does not necessarily imply that control of local spread is more important than control of long-distance spread. In the eastern United States, infection centers appear eventually to "die-out" for reasons not understood, so a control measure that would prevent all or nearly all long-distance spread could, over a period of years, be highly effective. However, since the level of disease control provided by any of these measures did not approach the absolute, those that were most effective against local spread produced the best record against total spread.

In addition to percentage control, the reduction in actual numbers of active centers per plot per year due to control efforts should be considered. In Pennsylvania, according to these results, 100 active wilt centers, if not treated, would produce about 45 active centers per year for the following several years. If the 100 active centers were treated and all active centers arising from them were treated as they appeared, only 11

TABLE 3.—Summary of oak wilt control by states ranked from best to poorest, 1959-1963

TOTAL SPREAD

State	Percent Control	State	Reduction in number of active centers per plot per year
Pennsylvania	76	Pennsylvania	0.34
West Virginia	50	West Virginia	.23
North Carolina-Tennessee	42	North Carolina-Tennessee	.09
Kentucky	-14	Kentucky	-.03

LONG-DISTANCE SPREAD

State	Percent Control	State	Reduction in number of active centers per plot per year
North Carolina-Tennessee	65	West Virginia	0.04
West Virginia	46	Kentucky	.03
Kentucky	27	North Carolina-Tennessee	.02
Pennsylvania	22	Pennsylvania	.02

LOCAL SPREAD

State	Percent Control	State	Reduction in number of active centers per plot per year
Pennsylvania	87	Pennsylvania	0.33
West Virginia	51	West Virginia	.19
North Carolina-Tennessee	39	North Carolina-Tennessee	.07
Kentucky	-54	Kentucky	-.05

active centers per year would be produced or an average annual reduction over no control of 34 centers per 100 original centers. Using the same example for West Virginia, 100 active centers would produce 45 active centers per year without control or 22 active centers per year with control for an average annual reduction of 23 centers per 100 original centers. In the North Carolina-Tennessee area, 100 active centers would produce only 22 active centers per year without control or 13 centers per year with control for an average annual reduction of 9 centers per 100 original centers.

Evaluation of control measures was also made on the basis of the number of wilting trees per plot per year on control plots as compared with check plots (table 4). The degree of control calculated by this method was slightly higher for Pennsylvania and North Carolina-Tennessee and slightly lower for Kentucky and West Virginia than that shown by the preceding infection-center method but the differences are small and do not alter the general evaluation and interpretation of results.

The importance of finding and treating infection centers in their first season of activity when they are small is clearly illustrated by the results of this study (table 5). Disease spread occurred more frequently around infection centers consisting of two or more wilting or wilt-killed trees (multiple center) than around infection centers consisting of a single, currently wilting tree (single center) on both control and no-control plots in all areas. The degree of control at both kinds of centers was about equal in Kentucky but in all other areas control was more effective against single centers than against multiple centers. This difference was greatest for the North Carolina-Tennessee treatment with 62-percent control on single centers and only 8-percent control on multiple centers. The degree of control in West Virginia was 55 and 33 percent and in Pennsylvania 87 and 73 percent against single and multiple centers, respectively.

The results of control as measured on the county-sized areas in Tennessee and Kentucky are somewhat difficult to interpret (table 6). In Tennessee, there were about twice as many active infection centers per square mile in the check county as in the control county when the study started. This ratio remained remarkably constant through the following 5 years suggesting that the control treatments had no influence on disease incidence. This conclusion is contrary to the results obtained on the smaller plots in the same area where disease spread was reduced 42 percent by the control treatments.

In Kentucky, there were more infection centers per square mile in the control county than in the check county when the study started but in four of the following five years there were fewer active centers per square mile in the control county than in the check county. This would indicate that the treatments had some effect in suppressing disease spread. Here again results are contrary to those obtained on the smaller

TABLE 4.—Number of wilt trees per plot by years since plot establishment, 1959-1963

KENTUCKY

Plot age (Years since establishment)	Control: Plots	Control: Wilt trees	Control: Trees per plot	No control: Plots	No control: Wilt trees	No control: Trees per plot
1	60	28	0.47	59	28	0.47
2	60	25	.42	58	11	.19
3	60	10	.17	57	13	.23
4	39	7	.18	35	2	.06
5	19	1	.05	18	0	0
Average per year	47.6	14.2	0.30	45.4	10.8	0.24
Reduction in number of wilt trees per plot per year						-0.06
Percent control						-25

NORTH CAROLINA-TENNESSEE

Plot age (Years since establishment)	Control: Plots	Control: Wilt trees	Control: Trees per plot	No control: Plots	No control: Wilt trees	No control: Trees per plot
1	52	10	0.19	37	15	0.41
2	52	12	.23	35	15	.43
3	48	8	.17	31	9	.29
4	30	1	.03	23	4	.17
5	22	2	.09	15	2	.13
Average per year	40.8	6.6	0.16	28.2	9.0	0.32
Reduction in number of wilt trees per plot per year						.16
Percent control						50

TABLE 4.—Number of wilt trees per plot by years since plot establishment, 1959-1963

PENNSYLVANIA

Plot age (Years since establishment)	Control			No control		
	Plots	Wilt trees	Trees per plot	Plots	Wilt trees	Trees per plot
1	55	14	0.25	60	46	0.77
2	53	9	.17	59	31	.53
3	40	4	.10	25	21	.84
4	27	1	.04	21	15	.71
5	10	1	.10	5	5	1.00
Average per year	37.0	5.8	0.16	34.0	23.6	0.69
Reduction in number of wilt trees per plot per year						.53
Percent control						77

WEST VIRGINIA

Plot age (Years since establishment)	Control			No control		
	Plots	Wilt trees	Trees per plot	Plots	Wilt trees	Trees per plot
1	70	40	0.57	60	46	0.77
2	69	22	.32	59	31	.53
3	68	21	.31	25	21	.84
4	45	11	.24	21	15	.71
5	15	6	.40	5	5	1.00
Average per year	53.4	20.0	0.37	34.0	23.6	0.69
Reduction in number of wilt trees per plot per year						.32
Percent control						46

TABLE 5.—Oak wilt control on single- and multiple-infection centers, 1959-1963

KENTUCKY

Treatment	Singe-infection centers: Plot years[1]	Singe-infection centers: Active center: years[2]	Singe-infection centers: Active centers per plot per year	Multiple-infection centers: Plot years	Multiple-infection centers: Active center: years	Multiple-infection centers: Active centers per plot per year
Control	116	22	0.19	122	28	0.23
No control	195	35	.18	32	7	.22
Reduction in number of active centers per plot per year			-0.01			-0.01
Percent control			-6			-5

NORTH CAROLINA-TENNESSEE

Control	131	10	0.08	73	16	0.22
No control	87	18	.21	54	13	.24
Reduction in number of active centers per plot per year			0.13			0.02
Percent control			62			8

PENNSYLVANIA

Control	63	3	0.05	122	17	0.14
No control	88	35	.40	82	42	.51
Reduction in number of active centers per plot per year			0.35			0.37
Percent control			87			73

WEST VIRGINIA

Control	194	35	0.18	73	25	0.34
No control	88	35	.40	82	42	.51
Reduction in number of active centers per plot per year			0.22			0.17
Percent control			55			33

1/ The sum of each plot multiplied by the number of years it was observed.
2/ The sum of the number of active centers each year for all years.

TABLE 6.—Oak wilt incidence in county-sized test areas, 1958-1963

KENTUCKY

Location	Number of active centers per 100 square miles 1/						
	1958	1959	1960	1961	1962	1963	Average
Lewis County							
(Control)	28	15	9	20	5	9	14
Greenup County							
(No control)	21	29	45	20	12	16	24

TENNESSEE

Greene County							
(Control)	14	11	10	13	9	9	11
Washington County							
(No control)	29	18	28	25	19	20	23

1/ Per 100 square miles forest land in Kentucky--per 100 square miles total land area in Tennessee.

plots in the same area where no evidence of disease suppression could be detected.

These contradictions cannot be completely rationalized. The accuracy of the surveys for these large areas was certainly less than that for the small areas and it is known that the intensity of ground coverage in the control county in Kentucky was unavoidably lower than that for the check county in Kentucky. The author is inclined to place more weight on the results obtained from the smaller plots where there were fewer uncontrolled variables, than on those obtained from the county-sized units. However, these disparities in results must reduce confidence in the accuracy of the evaluation of the control programs in both of these states. Perhaps the most meaningful information to be drawn from these county data is that no upward trend of oak wilt incidence could be detected during the 5-year-study period in large areas where no disease control was attempted.

The development of cost-benefit ratios is an important part of any continuing disease-control effort. The cost data presented here are only an initial step in developing this information (tables 7 and 8). "Costs per tree saved by control" are probably the most significant values listed in these summaries. They show the cost of a specific control program in one state under the prevailing level of effectiveness and disease incidence in that state in relation to only the immediate benefits. Any interpretations beyond this should be made with caution.

TABLE 7.—Costs for detection and control, 1958-1962

State	Wilt centers	Wilt trees	Costs		
			Total	Per center	Per tree
	Number	Number	Dollars	Dollars	Dollars
Kentucky	2,620	3,182	241,060	92.01	75.76
North Carolina	150	371	34,377	229.18	92.66
Pennsylvania	1,974	4,009	233,967	118.52	58.36
West Virginia	8,841	11,866	507,607	57.42	42.78

TABLE 8.—Cost-benefit statement for oak wilt control

	North Carolina	Pennsylvania	West Virginia
Average number of wilt trees per year	72	862	2,871
Estimated number of wilt trees per year with no control (factor from table 4)	144	3,717	5,354
Number of trees saved by control per year	72	2,855	2,483
Average annual cost of control	$6,719	$46,793	$101,521
Cost per tree saved	$93.32	$16.39	$40.89
Number of healthy trees destroyed by control per year	...	5,172	

The number of wilt trees with or without control is an annual average for the period of this study and does not show trends in disease incidence. The annual number of wilt trees on check plots in Pennsylvania-Maryland-West Virginia increased with time, so, to the extent that the Pennsylvania and West Virginia programs counteract this trend, they produce benefits only partially reflected in the cost-benefit statement. The fact that in Pennsylvania more healthy trees are being destroyed by the control treatments than would be immediately lost without control does not necessarily vitiate the program. If the trend of increasing wilt incidence measured on the check plots in that area were to continue throughout the State, within a few years disease losses would greatly exceed the value of trees destroyed in keeping the disease at its present level.

The cost for aerial survey of an area increases as the number of diseased trees in the area increases, but at much less than a directly proportional rate. When the costs are expressed as dollars per diseased tree found, they will obviously be lower for the heavily infected area. Unfortunately, costs for survey could not be separated from costs for control for these programs so the "cost per tree saved" reflects not only the efficiency and effectiveness of the programs but is also influenced, through survey costs, by the level of disease incidence in the State. The high unit cost of control in North Carolina is likely due in part to the relatively low incidence of disease in that area.

To decide whether any of these control programs are economically sound will require more information than is now available. The foregoing discussion points out some of the factors that must be considered in such an analysis.

CONCLUSIONS

There is no way, in this evaluation, to appraise the biological soundness of a control method separately from the manner in which it was applied. Rather, this provides an overall measure of the effectiveness of a disease-control program as it was carried out. Only general comparisons can be made between the different programs and methods since each was applied and evaluated in a different area. We cannot be sure that they would produce similar results in other sections of the country. Also, the costs for labor, materials, equipment, and healthy trees destroyed varies between methods and these must be balanced against the degree of control achieved. With these qualifications, the following conclusions appear warranted.

The rate of uncontrolled oak wilt spread, as measured on the check plots, was not overwhelming in any of the study areas. Further, no increase in this rate could be detected during a 5-year period in two counties in Tennessee and Kentucky in which no control was attempted. Results from the check plots in Tennessee and Kentucky support this observation. Wilt incidence on the Pennsylvania-Maryland-West Virginia check plots, on the other hand, was somewhat higher and showed definite indications of an upward trend. If this is a continuing trend, the disease situation there could, without control, become severe in a short time. The apparent tendency for oak wilt incidence to steadily increase in this area may be the single most important finding of the study.

Oak wilt spread was appreciably reduced by the control programs in Pennsylvania (76 percent), West Virginia (50 percent), and North Carolina-Tennessee (42 percent). Because this disease has a history of erratic behavior we still cannot predict with great confidence what future disease losses might be for any area not under control. On the basis of current knowledge, however, we must assume that disease damage would become intolerable in Pennsylvania and West Virginia without the counteracting effect of their respective control programs and that these programs, therefore, are fully justified. Justification of the North Carolina-Tennessee program may be questionable, not necessarily because of any particular weakness in the method or the manner in which it was applied but because of the apparent low potential for disease spread in that area. The Kentucky program did not prove to be effective in these studies but there, also, the potential for uncontrolled-disease damage appears to be low.

Disease survey is an essential part of any control program. Obviously, infected trees must be found before they can be treated so the level of oak wilt control is not likely to be any higher than the level of oak wilt detection. Small, new, oak wilt centers are more amenable to control than large, old centers. Improvements in detection that will permit "hitting" the singles before they become multiples will also improve control effectiveness.

Most oak wilt spread is to trees within 50 feet of previously diseased trees. This may be a normal pattern for spread of the fungus by nitidulid beetles or small oak bark beetles, the two insects most commonly conceded to be oak wilt vectors. It might also suggest that spread through root grafts may be more important in the eastern range of the disease than is generally recognized. Whatever the cause, to better explain this pattern of spread and how to modify control methods for more effective suppression of local disease transmission would appear to warrant high priority in any oak wilt research program.